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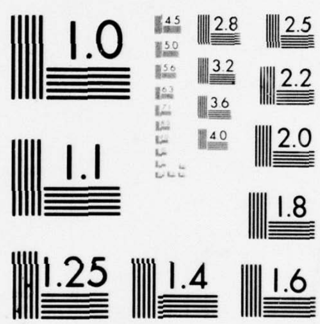

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 19 15277.1-A-P 18 ARO	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 Investigation of Millimeter Wave and Far Infrared Multiwavelength Systems		5. TYPE OF REPORT & PERIOD COVERED 9 Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 G. R. Loefer R. G. Shackelford		8. CONTRACT OR GRANT NUMBER(s) DAAG29-77-C-0026, new 15 N00014-75-C-0320
9. PERFORMING ORGANIZATION NAME AND ADDRESS Georgia Institute of Technology - 410657 Atlanta, Georgia 30332 Electromagnetics Lab		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Office P. O. Box 12211 Research Triangle Park, NC 27709		12. REPORT DATE 11 22 February 1978
		13. NUMBER OF PAGES 19 12 21p.
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Millimeter waves	Lasers
Electro-optical systems	System design
Sensors	Submillimeter waves
Radar	Heterodyne detection

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Under a previous contract, a series of tests were performed in an effort to define some of the working characteristics of the 70 GHz radar and to investigate some of the problems involved with 'handover' from the radar to an electro-optical (EO) sensor system. These experiments are discussed in this report. An EO system with the desired performance can be realized with a 5 watt CW laser. With direct detection, the performance margin is low even in high visibility atmospheric conditions; however, with heterodyne detection, adequate SNR will exist to compensate for losses in the optical system, and atmospheric losses associated with low to moderate visibility conditio

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INTERIM TECHNICAL REPORT

"INVESTIGATION OF MILLIMETER WAVE
AND
FAR INFRARED MULTIWAVELENGTH SYSTEMS"

ARO Contract No. DAAG29-77-C-0026
(GT/Project No. A-1985)

Prepared for

U. S. Army Research Office
Post Office Box 12211
Research Triangle Park, N. C. 27709

Prepared by

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for

Georgia Institute of Technology
Engineering Experiment Station
Electromagnetics Laboratory
Atlanta, Georgia 30332

February 22, 1978

SYSTEMS ANALYSIS

A. BACKGROUND

Under Contract No. N00014-75-C-0320 a series of tests was performed in an effort to define some of the working characteristics of the 70 GHz radar and to investigate some of the problems involved with "handover" from the radar to an electro-optical (EO) sensor system. These experiments are discussed in Appendix A, which is a copy of a paper presented by EES personnel to the Sixth Annual Tri-Services Submillimeter Conference. The important result of those tests was that targets displayed could be located by an operator-positioned cursor to within a standard deviation of 0.5 mrad. to 1.0 mrad. total error, even though the radar had a 9.6 mrad. beamwidth. In view of these results, the EO system design was based on the assumption that a target's line-of-sight (LOS) could be determined to within $\pm$ 1 mrad. If the EO system scans a 3 mrad. field-of-view (FOV), the target should always be located within the FOV immediately after handover. Tests with a zoom telephoto - TV system mechanically boresighted to the radar showed that this was indeed a reasonable assumption.

B. SYSTEM DESIGN

The basic considerations for design of an active CO_2 system involve performance trade-offs between pulsed versus CW operation, and between heterodyne versus direct detection. The availabilities of funds, off-the-shelf components, and time were also considered. It was assumed for a concept demonstration system that the effects of atmospheric attenuation could be minimized by restricting operations to high visibility meteorological conditions.

In order to make a quantitative, as well as qualitative judgement of the relative merits of each of the possible system configurations, the criterion of maximum target range for a signal-to-noise ratio of one in clear, dry air (0.4 dB/km attenuation coefficient) was used in the comparison calculations. An attempt was made to determine available and near-term-projected performance limits on as many parameters as possible. In addition to the maximum range calculations, the different advantages and disadvantages of pulsed versus CW systems were considered in a qualitative manner. It should be emphasized that these calculations were for comparison purposes - not absolute prediction of system performance.

C. THE RANGE EQUATION

One of the simplest configurations for an active EO system is to have the output of the laser directly "floodlight" the scene while the receiver scans the scene with a much smaller instantaneous field-of-view (IFOV). This requires no scanning of the laser beam, but does require more laser power because the transmitter and receiver FOV's are not matched.

The purpose of the range equation is to determine the maximum range at which a particular system signal-to-noise ratio (SNR) would allow target detection. It has been assumed that the laser output power is P_o, with a beam divergence of θ_B, where P_o represents the average or rms power of a CW laser, or the peak power of a pulsed laser averaged over one cycle of the output waveform. The beam illuminates a target at a range R, and for this application, the target is assumed to be larger than both the transmitted beam (θ_B) and receiver IFOV. Also, both θ_B and IFOV are considered small enough so that the angles themselves can be used in place of their sines or tangents, as appropriate. If the atmospheric extinction coefficient is α, then the power of the transmitted beam at the target, P_T is given by

$$P_T = P_o \, e^{-\alpha R}$$

The irradiance produced by the laser at the target, I_T, is P_T divided by the area of the beam at the target,

$$A_T = \frac{\pi}{4} \theta_B^2 R^2$$

or

$$I_T = \frac{4 P_o e^{-\alpha R}}{\pi \theta_B^2 R^2} .$$

If the target is assumed to have a Lambertian diffuse reflection coefficient* of $\rho = .1$, the radiance of the target

$$W_T = \rho \ I_T = \frac{4 \ \rho \ P_o \ e^{-\alpha R}}{\pi \ \theta_B^2 \ R^2} \ .$$

the power collected by the receiver would be

$$P_d = \frac{W_T}{\pi} \ \frac{A_o \ \tau_o \ \pi \ (IFOV)^2 \ e^{-\alpha R}}{4} \ ,$$

where A_o = area of the collecting optics

τ_o = total optical transmission of optics,

so that $$P_d = \frac{\rho \ P_o \ A_o \ \tau_o \ (IFOV)^2 \ e^{-2\alpha R}}{\pi \ \theta_B^2 \ R^2} \ .$$

The signal voltage out of the detector is

$$Vsig = R_s \ P_d \ ,$$

where R_s is the detector responsivity given by

$$R_s = \frac{Vnoise \ D^*}{A_d \ B_n} \ ,$$

Vnoise = noise voltage,

D* = detector detectivity,

A_d = detector area, and

B_n = noise bandwidth of the electronics.

*Data taken at close ranges with an active CO_2 system by U. S. Army MIRADCOM indicate highly specular reflections (glint) with fluctuations on the order of 40 to 70 dB. Thus, ρ may be much higher or lower at a given target aspect. US MIRADCOM Technical Report TR-77-2 1 February 1977.

The signal-to-noise ratio is then given by

$$\mathrm{SNR} = \frac{V_{sig}}{V_{noise}} = \frac{R_s P_d}{V_{noise}} = \frac{D^*}{A_d B}$$

$$= \frac{\rho\, D^*\, A_o\, \tau_o\, \tau_t\, (\mathrm{IFOV})^2\, e^{-2\alpha R}}{A_d^{1/2}\, B^{1/2}\, \pi\, \theta_B^2\, R^2}$$

$$= C_1 \frac{e^{-2\alpha R}}{R^2}$$

where τ_T is the degradation in signal due to atmospheric turbulence.

The equation can be rewritten in a form suitable for solution for R by numerical methods as

$$\frac{e^{-2\alpha R}}{R^2} \cdot C_1 - \mathrm{SNR} = 0.$$

D. SYSTEM COMPARISONS

The radar pointing accuracy as determined in previous tests and the desired EO sensor resolution determine the FOV and the IFOV, respectively. These two terms in turn determine the number of resolution cells per frame. Since the radar pointing accuracy had been measured to be $\pm$ 0.5 to $\pm$ 1.0 mrad., a 3 mrad. FOV was selected to allow a sufficient margin to assure that the target was in the FOV at the instant of handover. From other considerations, which included mount stability and diffraction phenomena, a 0.1 mrad. IFOV was selected as the resolution goal. These parameters indicate a 30 x 30 point resolution field. Since the detected and processed signal was to be visually displayed, a minimum frame rate of 20 Hz was also selected. This gives a data rate of 18 kHz, requiring a bandwidth, B, of 18 kHz.

E. CANDIDATE SYSTEMS

Several system configurations were considered: a. CW laser floodlight, 5 and 20 watt output power, combined with a narrow IFOV receiver with direct detection; b. CW laser, employing a common aperture transmitter-receiver and direct detection; c. Pulse laser, also in a common aperture configuration with direct detection; d. CW laser, employing a common aperture with heterodyne detection.

In considering the possible systems implementation configurations, operation in a pulsed mode has several advantages over a CW system. Because the range to the target is already well determined by the radar (accurate to about 3 m.), this information could be used to gate the pulsed return signal to reduce both clutter and atmospheric backscatter. On the other hand, current generation pulse lasers designed for target designation have adequate energy (>100 mJ) for the subject application but are usually found to run at pulse repetition rates <50 Hz with a typical average power of several watts. At 50 Hz, it would take approximately 18 seconds to generate a 30 x 30 point scene with one pulse per resolution cell. Because of problems associated with pulsed lasers, it was decided to proceed with the purchase of a CW laser.

A choice then had to be made between using a 20 watt CW laser, whose cost would preclude anything but a floodlight mode or using a 5 W laser which would also allow the purchase of beam scanning equipment. Other calculations were made to compare as well as possible CW direct detection versus pulse direct detection and CW direct detection versus CW heterodyne detection. During these comparisons, as many parameters as possible were kept constant to minimize confusion. These parameters were as follows: diameter of optics 8 in.(0.2032 m.), focal length 32 in., laser beam divergence 3 mrad., atmospheric extinction ratio (α) 0.4 dB/km (.0921 km^{-1}), frame rate 20 Hz, IFOV - 0.1 mrad., FOV = 3 mrad., D^* 3×10^{10} cm $Hz^{1/2}$ W^{-1}, detector size 0.015 cm (diameter), $\tau_t = 0.8$, $\tau_o = 0.2$, $\rho = 0.1$. These values were all judged to be conservative estimates except for the atmospheric extinction coefficient, which corresponds to clear, dry air. Again, these calculations were for comparison and not meant to predict absolute system performance.

System A: With direct detection, floodlight mode, and a CW laser with 5 and 20 watt output,

$$SNR = \frac{D^* (IFOV)^2}{A_d^{1/2} \; B^{1/2}} \cdot \frac{D_o^2 \; \tau_o}{4} \cdot \frac{P_o \; \rho}{\theta_B^2} \cdot \frac{\tau_t \; e^{-2\alpha R}}{R^2}$$

therefore $C_1 = 3.09 \times 10^3 \; P_o$

when SNR = 1 and C_1 (5 watt) $= 1.54 \times 10^4$ $R_{max} = 123$ m.

C_1 (20 watt) $= 6.18 \times 10^4$ $R_{max} = 243$ m.

Both maximum ranges are unacceptable, thus requiring moderate beam expansion. This precludes using the 20 W laser without beam expansion (notice also that maximum range was less than doubled for quadruple the power output).

System B: The next consideration involved scanning both the transmitter and receiver with the same IFOV and examining the potential for adequate range performance with the 5 W CW laser. Expanding the laser beam by a magnification factor, M, reduces the beam divergence by the same factor. The most efficient magnification is that which matches the laser beam size to the receiver IFOV. With a beam divergence of 3 mrad. and an IFOV of 0.1 mrad., this requires M = 30. Then

$$SNR = SNR \text{ (3 mrad.)} \times M^2$$

or

$$C_1 = 1.39 \times 10^7$$

and

$$R_{max} = 2.86 \text{ km.}$$

This is quite sufficient for demonstration purposes (being aware of the fact that actual implementation of the system will probably yield somewhat lower performance).

<u>System C</u>: Assuming that sufficiently high repetition rates could be attained, the range calculation for a pulse laser, direct detection system was made for two peak powers, P_p = 1 kW and 1 MW, assuming a 100 nsec. pulse ($\tau_p = 100 \times 10^{-9}$ sec). The SNR for pulse systems is the same as that for CW systems with the following substitutions: $P_o = P_p$ and $B = \frac{1}{2\tau_p}$. In this case $B = \frac{1}{200 \times 10^{-9}} = 5$ MHz (this is compatible with HgCdTe detector operating in the photovoltaic mode) and $P_p = 10^3$ W and 10^6 W

therefore

$$C_1 = 5.27 \times 10^6 \text{ (1 kW)}$$

$$R_{max} = 1.93 \text{ km}$$

$$C_1 = 5.27 \times 10^9 \text{ (1 MW)}$$

$$R_{max} = 16.3 \text{ km}$$

Obviously these ranges are unrealistic in that system performance at these ranges will not be limited by SNR, but by other factors such as diffraction limit of optics, target filling beam, atmospheric backscatter, etc.

<u>System D</u>: With heterodyne detection, SNR is no longer detector-limited, but background-limited. Also, the bandwidth, B, must be increased to allow for spectral instabilities in laser frequency. The specifications for the 5 watt laser give this bandwidth as

$$B_H = 6 \text{ kHz short term } (< 0.1 \text{ sec})$$

$$B_H = 5 \text{ MHz long term } (> 10^3 \text{ sec})$$

In the short term case, the heterodyne bandwidth is actually less than that required to pass the raster information, and should therefore be added to B to give

$$B_H \text{ (short term)} = 24 \text{ kHz}$$

$$B_H \text{ (long term)} = 5 \text{ MHz.}$$

The relation between SNR for direct detection, SNR_D, and SNR for heterodyne detection, SNR_H, is

$$SNR_H = SNR_D \cdot \frac{\eta \ \lambda \ A_d^{1/2} \ B^{1/2}}{2h \ c \ \pi \ B_H \ D^*}$$

where

η = (.2) detector quantum efficiency

λ = laser wavelength

B_H = direct detection bandwidth

h = Plank's constant

c = speed of light

D^* = detector detectivity

this gives

$$C_1 = 5.84 \times 10^{10}$$

$$R_{max} = 24.7 \text{ km (short term)}$$

$$C_1 = 2.81 \times 10^{8}$$

$$R_{max} = 5.02 \text{ km (long term)}$$

Again, reservations about these ranges are the same as those for the pulse system.

CONCLUSIONS

It appears that the desired system performance can be realized with the 5 watt CW laser. With direct detection, the performance margin is low even in high visibility atmospheric conditions; however, with heterodyne detection, adequate SNR will exist to compensate for losses in the optical system, and atmospheric losses associated with low to moderate visibility conditions.

FUTURE GOALS

From these conclusions, a multiphase program has been planned by ERADCOM and Georgia Tech personnel. The first phase is to demonstrate the electronic handover using cursor-located target coordinates from the radar to position a gimballed beam-steering mirror for the E-O system. The E-O system will be simulated by a telephoto TV system and/or a HeNe laser. The second phase will involve building and testing the CW, direct detection system. The third phase will modify the system to use heterodyne detection.

PRESENTED TO

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Washington, D. C. November, 1977

APPENDIX I

COMBINED ELECTRO-OPTICAL/MILLIMETER WAVE RADAR SENSOR SYSTEM

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ABSTRACT

A combined electro-optical/millimeter wave radar sensor system is described and the results of preliminary field tests with this system are presented. The electro-optical sensor is a conventional television camera. Future modifications of this system, which includes installing a pulsed laser radar as the electro-optical sensor and future plans for this program are discussed.

I. INTRODUCTION

Tactical surveillance and weapon guidance systems depend critically on the Army's ability to not only acquire, but also to identify and to precisely locate targets of military significance. Conventional microwave radars have traditionally fulfilled the target acquisition role for the Army. However, due to resolution limitations inherent in the microwave frequency domain, these radars have met with limited success in target identification and precise target location required for accurate weapons delivery. To overcome these inherent inadequacies in radar systems, there has recently been a rapid emergence of electro-optical (EO) sensors, such as low-light-level television, forward looking and other infrared sensors and laser radar. Since these devices operate at, or are sensitive to, frequencies in the infrared to visible region of the electromagnetic spectrum, they have a much greater resolution than that of microwave radars and thus are able to more adequately fulfill the target identification and precise target location roles.

Two basic limitations of EO sensors prevent these sensors from completely replacing the radar sensor in tactical operations. First of all, EO sensors are inadequate in a search and target acquisition role due to the length of time needed for these extremely high resolution sensors to scan a given spatial volume. Secondly, EO sensors suffer much higher atmospheric attenuation losses than microwave sensors, especially in degraded weather conditions or in a smoke, fog or aerosol environment. Under these atmospheric conditions and without a microwave radar aboard, an Army vehicle, e.g., tank, would literally be "blind" to its surroundings.

To overcome the individual inadequacies of the two sensor systems and at the same time take advantage of their respective capabilities and strengths, both sensors can be utilized together in an augmenting fashion to form a combined electro-optical/radar sensor system. With this in mind, the Engineering Experiment Station (EES) at the Georgia Institute of Technology recently began a multi-phase program under contract with the U. S. Army ERADCOM to demonstrate the feasibility of such a combined EO/millimeter wave radar sensor system. In this dual sensor system, the millimeter wave radar system performs its conventional role of searching large spatial volumes in order to acquire and crudely locate a target. Once the target is acquired, the higher resolution EO sensor is directed toward the target for identification, accurate and precise target location and weapons delivery.

The ultimate goal of the program is to have for the EO sensor a pulsed, heterodyned CO_2 laser radar suitable for weapon guidance. In Phase I of the program, which is nearing completion, basic interfacing problems between the two sensors are being investigated. A conventional television camera (vidicon) and monitor are being used to simulate the laser radar. In this paper, the preliminary results of this initial phase of the program are discussed and the plans for future phases are reviewed. In Section II, the combined EO/millimeter wave sensor system itself is discussed. In Section III, Phase I of the program is discussed, the results of the preliminary field tests with the combined sensor system are presented and some of the EO/Radar interfacing problems discussed. Finally, in Section IV, future plans for the program, including those involving the laser radar sensor, are reviewed.

II. EO/MILLIMETER WAVE RADAR SENSOR SYSTEM

The radar system used in the combined dual sensor system is Georgia Tech's 70 Ghz (4.3 mm), high-resolution, rapid scan radar originally built by EES for Harry Diamond Laboratories. This radar was made mobile by installing it in a M-109 shop van. The radar console and antenna are linked together and revolve about a common axis. The operator faces the direction illuminated by the radar and a periscope, whose optical axis is aligned with the antenna electromagnetic axis, provides him with an optical view of the illuminated area. The basic system parameters of this radar are given in Table I.

The radar antenna assembly was recently modified by the addition of two microwave reflectors (see Figure 1). When in use, these reflectors essentially rotate the microwave beam through 90° upon leaving the antenna, thus enabling the radar to operate in a vertical scan mode. To activate the vertical scan mode, the tiltable plane reflector-mirror assembly (see Figure 2) must be folded back toward the antenna so that the microwaves can reach the vertical scan reflectors. While in the vertical scan mode, the EO sensor is inoperative.

The EO sensor is a conventional television (TV) camera (vidicon) which is mounted in the van and aligned with the periscope so that the EO optical axis and radar microwave axis are mechanically co-boresighted in azimuth (see Figures 2 and 3). Attached to the camera is a lens with variable magnification from x15 to x60 corresponding to a field-of-view from approximately 14.2 mrad to 3.5 mrad. Another TV camera is focused on the radar display and the outputs from the two cameras are fed into a special effects generator which in turn is connected to a video tape recorder and monitor (see Figure 4). Thus, the radar display and optical imaging can be displayed together in a "split-screen" effect.

III. PHASE I OF THE PROGRAM AND RESULTS OF THE PRELIMINARY FIELD TESTS

A. Phase I of the Program

In Phase I of the program, basic interfacing problems between the two sensors are being investigated. These problems include:

1. Determination of the minimum angular uncertainty in target location achievable with the radar sensor alone, and
2. Determination of the best method of coupling the two sensors together.

The basic target locating accuracy of the radar in a clutter and multipath environment is of critical importance in determining the field-of-view (FOV) to be scanned by the laser radar. Because of the large amount of time required by the laser to scan large spatial volumes, the FOV must be kept to a minimum. Therefore, a determination must be made of the minimum angular uncertainty in target location achievable with the radar.

There are several ways to "handoff" from the radar to the EO sensor, i.e., several methods of coupling the two sensors together. These methods vary from a system where the laser sensor is on a set of gimbals and is electronically coupled to the radar, to a system where the coupling is done both electronically and mechanically, to a totally mechanically coupled system. As was mentioned in Section II, for feasibility demonstration purposes the EO sensor is currently mechanically coupled to the radar in azimuth with no coupling in elevation.

B. Results of the Preliminary Field Test

Preliminary calibration/shake-down field tests of the combined EO/Radar sensor were conducted at Ft. Gillem, Georgia on 20-30 Sept., 1977. The tests were conducted in a field with relatively flat terrain bounded with trees on either side and with a range of over 1200 meters.

The beamsplitting experiments consisted of simply having the radar operator center the azimuth or elevation cursor on the target return as displayed on a B-scope. The angular placement of the cursor was then compared to the true angular position of the target as measured with a theodolite located in the antenna assembly. No attempt was made on these initial series of field tests to eliminate the human factor and its affect on the test results. Targets included both corner reflectors and a small pick-up truck. Results of these tests are summarized in Table II. Within one standard deviation, a target could be located in both azimuth and elevation to an accuracy of approximately 1 mrad. Given the radar's 9.6 mrad beamwidth, this represents roughly a 9:1 beamsplit.

Finally, to demonstrate the overall feasibility of combining an EO sensor with a radar sensor, several "handoff" experiments were performed. The EO and radar boresights were aligned and then several targets were acquired by the radar. Once a target had been acquired and aligned on the radar's boresight, the EO sensor was activated to determine whether or not the target was in the EO sensor's FOV, and if so, to identify the target. During these tests, the EO sensor was kept at its maximum FOV. The combined sensor system performed very well during these tests with the target being well centered on the monitor. Several video tape recordings were taken from which two still frames are shown in Figures 5 and 6.

IV. FUTURE PLANS FOR THE PROGRAM

In the remainder of Phase I of the program, which will terminate on 31 Jan. 1978, extensive field tests will be conducted in which the minimum angular uncertainty in target location achievable with the radar will be precisely determined. This data will be operationally checked by actually conducting various "handoff" experiments in which the FOV of the TV camera will be varied in order to simulate different possible FOV's being scanned by the laser sensor. In this way, the actual FOV to be scanned by the laser sensor can be determined. Based on preliminary results, a 3 mrad FOV is currently being planned. In addition, a determination will be made in this phase of the program as to the best method of coupling the two sensors together.

In Phase II of the program, which is already underway, a CW CO_2 laser sensor system will be constructed and integrated with the radar. Within the next three months this integration will be completed, with a He-Ne laser simulating the CO_2 laser. In four to six months, a CW direct detection system will be operative with:

1. a 5 watt CW CO_2 laser,
2. a resolution cell of 0.1 mrad, total FOV 1 mrad
3. a frame rate of 20 hz

In 10 to 18 months, a CW heterodyned receiver will be operative with a second laser as L.O.

In Phase III of the program, a pulsed, heterodyned CO_2 laser radar will be developed as the EO sensor. This sensor will have a 5 KW or greater peak power, 18 Khz PRF and a CW laser as L.O.

ACKNOWLEDGMENTS

The authors wish to acknowledge the following people for their contributions to this program: N. T. Alexander, J. E. Davidson, J. A. McKenzie and S. Y. Willis.

TABLE I. BASIC RADAR SYSTEM PARAMETERS

1. ANTENNA: FOLDED, GEODESIC LENS FEEDING A PARABOLIC CYLINDER REFLECTOR. THE ANTENNA IS 25 INCH DIAMETER BY 3.5 INCH HEIGHT. GAIN: 43.2 dB (CORRECTED FOR LOSS)

2. SCANNING MODES: SCANNING BY A SEVEN RING SWITCH WHICH ALLOWS A SCAN RATE OF APPROXIMATELY 1 RPM TO 50 RPS

   AZIMUTH SCAN MODE:

   SCAN ANGLE: 45° (±22.5° ABOUT BORESIGHT)
   AZIMUTH BEAMWIDTH: 0.55° (POSITIONABLE THROUGH 360°)
   VERTICAL BEAMWIDTH: 3.5° (POSITIONABLE FROM -10° TO 20°)

   VERTICAL SCAN MODE

   SCAN ANGLE: -5° TO 10° (APPROXIMATELY)
   AZIMUTH BEAMWIDTH: 3.5° (POSITIONABLE THROUGH 360°)
   VERTICAL BEAMWIDTH: 0.55° (POSITIONABLE THROUGH ±5°)

3. TRANSMITTER:

   MAGNETRON: BOMAC BL 234C
   PEAK POWER: 500 WATTS
   FREQUENCY: 69 TO 71 GHz
   RF PULSE WIDTH: 20 AND 45 NANOSECONDS (ADJUSTABLE)
   PULSE REPETITION FREQUENCY: 5 KHz TO 25 KHz (VARIABLE)
   MODULATOR: TRIGGERED BLOCKING OSCILLATOR
   DUPLEXER: BOMAC BL-P-017D

4. RF COMPONENT LOSS: 6 dB (TOTAL)

5. LOCAL OSCILLATOR: VARIAN VA 250 KLYSTRON

6. MIXER: PHILCO IN2792 MIXER CRYSTAL; CONVERSION LOSS 15 dB
   EQUIVALENT NOISE FIGURE 18 dB MINIMUM
   EQUIVALENT NOISE FIGURE WITH IF 25 dB MAXIMUM

7. IF: GAIN: 70 dB
   CENTER FREQUENCY: 400 MHz
   BANDWIDTH: 60 MHz
   NOISE FIGURE: 5 dB

8. VIDEO AMP:

   BANDWIDTH: 50 MHz
   GAIN: 150 (VOLTAGE)

9. DISPLAYS-INDICATOR UNITS:

   SECTOR SCAN
   B-SCAN MODE
   NON-COHERENT DOPPLER AURAL DISPLAY

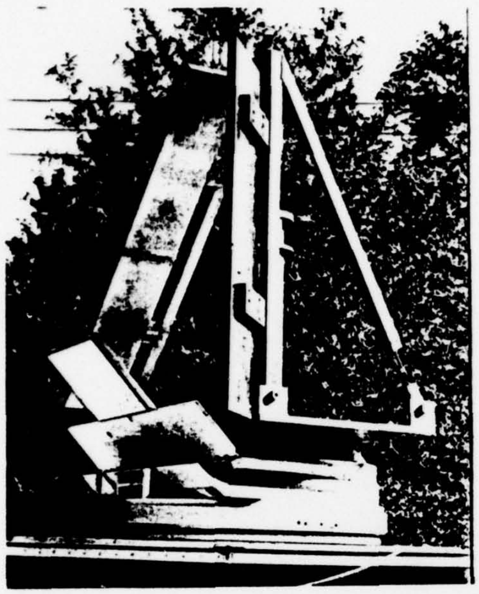

Figure 1. 70-Ghz Antenna Assembly With Vertical Scan Reflectors Mounted On Top Of Geodesic Lens Antenna

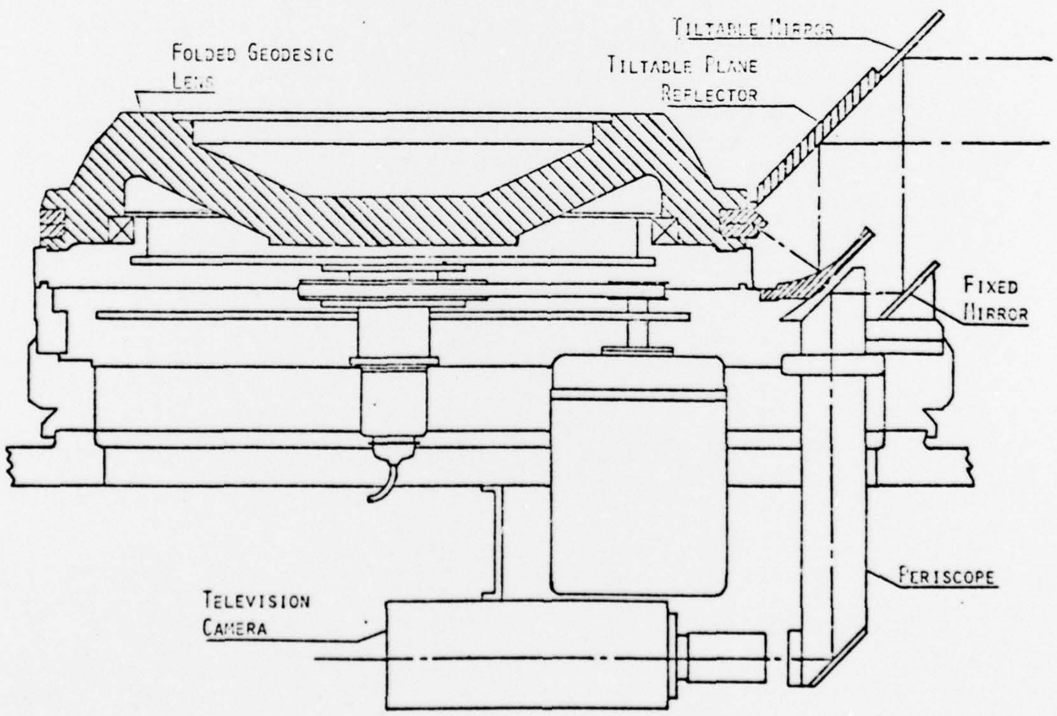

FIGURE 2. 70-GHz FOLDED GEODESIC LENS ANTENNA WITH TV CAMERA MOUNTED FOR VIEWING THROUGH PERISCOPE

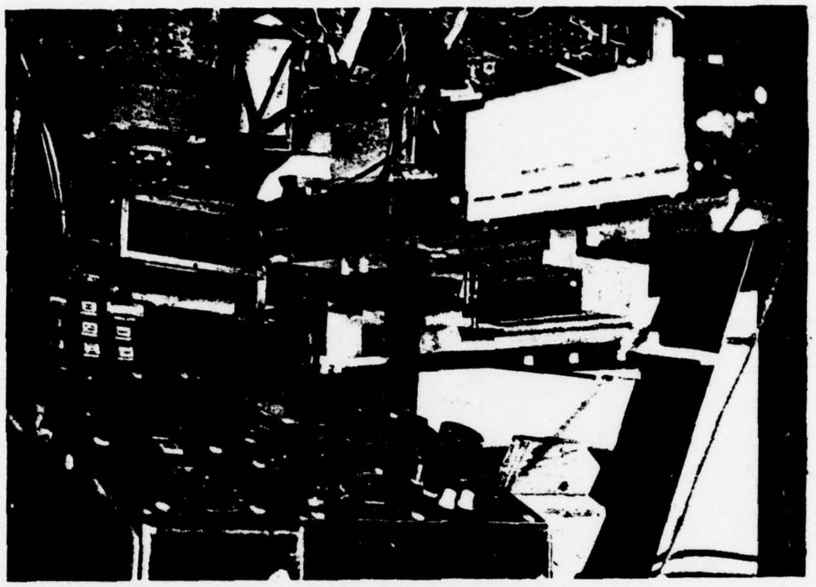

Figure 3. TV Camera Aligned With Periscope And Radar Display And Controls (2nd TV Camera Not Shown)

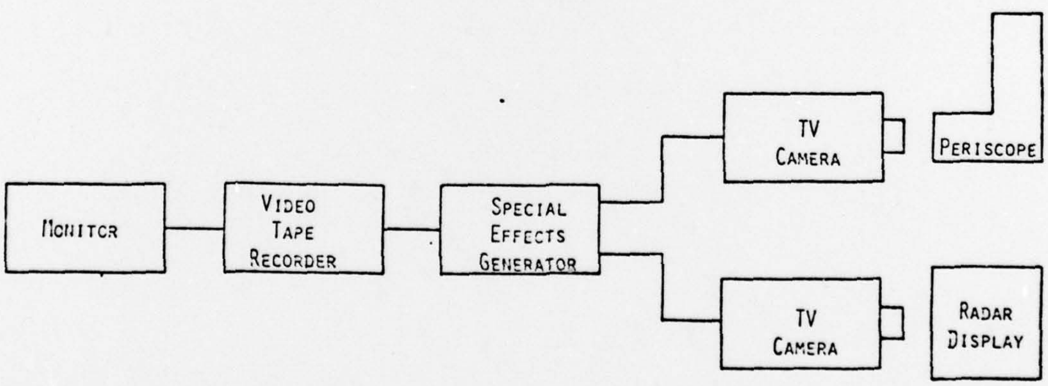

FIGURE 4. SCHEMATIC DRAWING OF EO/RADAR MONITORING AND RECORDING SYSTEM

TABLE II. BEAMSPLITTING RESULTS FROM PRELIMINARY FIELD TESTS

ELEVATION BEAMSPLITTING

TARGET	NO. OF TRIALS	RANGE (M)	RESOLUTION (ONE STANDARD DEVIATION)
CORNER REFLECTOR	30	168	1.047 MRAD
CORNER REFLECTOR	30	168	1.066 MRAD
TRUCK	6	112-408	0.544 MRAD
TRUCK	8	455-1026	1.009 MRAD

AZIMUTH BEAMSPLITTING

TARGET	NO. OF TRIALS	RANGE (M)	RESOLUTION (ONE STANDARD DEVIATION)
CORNER REFLECTOR	30	356	1.117 MRAD

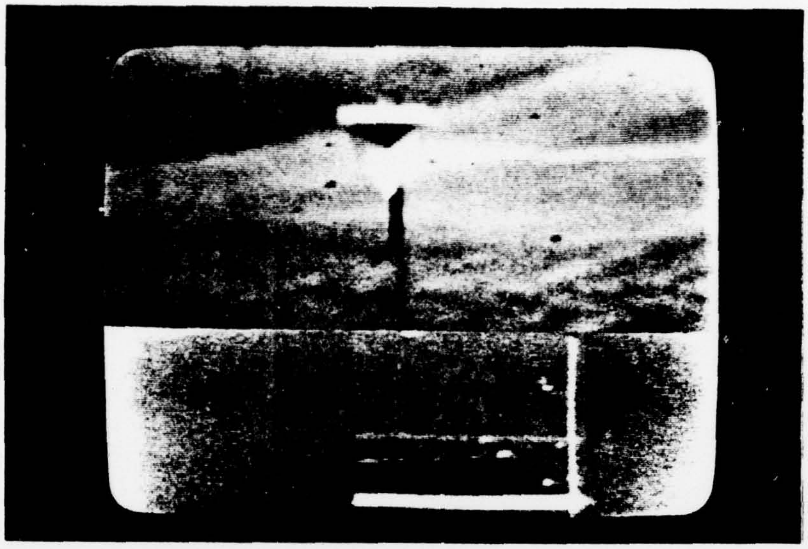

Figure 5. Still Frame Photo Of Video Tape Recording Showing Split Screen Of Corner Reflector As Simultaneously Imaged By EO Sensor (Top) And Displayed By Radar On B-Scope

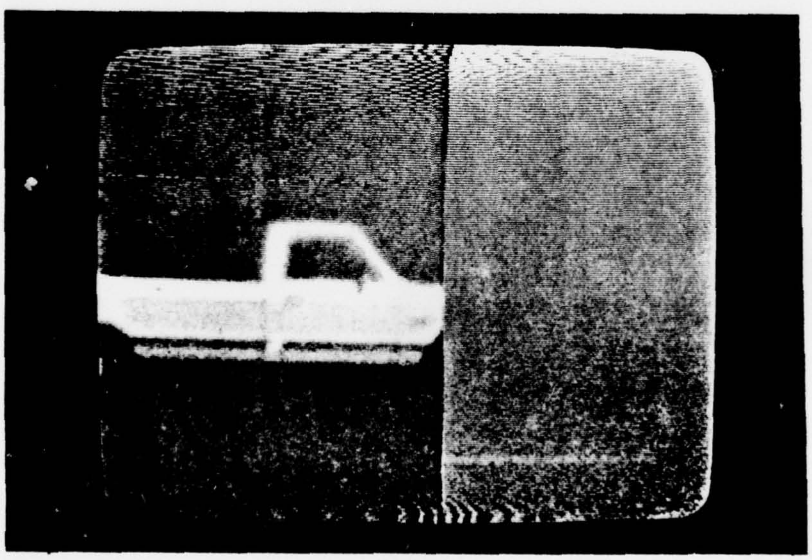

Figure 6. Still Frame Photo Of Video Tape Recording Showing Split Screen Of Truck As Simultaneously Imaged By EO Sensor (Left) And Displayed By Radar On B-Scope